# Life Prediction for FRP composites with Data Fusion & Machine Learning

Completed Technology Project (2015 - 2016)

## Project Introduction

High-fidelity, probabilistic predictions of damage evolution in fiber-reinforced polymer (FRP) composite structures could accelerate development and certification of new concepts through a reduction in the need for physical testing and an increase in structural health awareness. Unfortunately, high-fidelity models often carry the burden of excessive computation times. Probabilistic damage prognosis involves fusing structural health data with physics-based models using what are sometimes referred to as inverse uncertainty quantification techniques. Here, model parameters that cannot be determined directly are calibrated based on measurement data, and the associated parameter uncertainties are simultaneously quantified. However, these techniques require thousands or even millions of simulations to converge, which compounds the computational problem associated with high-fidelity models. The current state-of-the-art in damage prognosis avoids this issue through a simplification of the damage models, which in turn sacrifices the potential of these predictions to significantly impact research and development at NASA. This proposal aims to achieve a high-fidelity, probabilistic predictive capability for FRP composites utilizing data fusion, advanced modeling and simulation, and machine learning.

**Objective**: Reach beyond the state-of-the-art utilizing machine learning and data fusion to enable probabilistic life predictions for real-world structures comprised of fiber-reinforced polymer (FRP) composite materials.

**Problem:** Accurately predicting the remaining life of these structures requires the integration of high-fidelity damage progression models, uncertainty quantification (UQ), and inverse uncertainty quantification (iUQ) for data fusion (e.g., Markov chain Monte Carlo methods). Unfortunately, state-of-the-art, high-fidelity damage models can be excessively time consuming which often prohibits their use with standard iUQ methods (e.g., a predictive analysis with 10,000 simulations, each with a runtime of ~3 hours, would take on the order of years to complete). The issue is further complicated in that parallelization of iUQ techniques is inherently restricted.

**Current Practice:** Probabilistic life predictions are typically conducted using simplified one- or two-dimensional analytical models that are time-efficient for use with iUQ. However, these models sacrifice fidelity and are generally incapable of representing damage evolution in real-world structures that are complex in geometry, loading, and material. Damage in these structures is subject to mixed-mode driving forces and progresses in three-dimensions.

**Innovations: (1)** The aforementioned issue of prohibitive computation times will be addressed using surrogate models in place of time consuming finite element analyses (FEA). Structural health monitoring data will then be fused with the proposed high-fidelity damage modeling framework to form probabilistic life predictions for real-world structures using iUQ. Based on initial estimates, prediction times have the potential to be reduced by almost


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## Table of Contents



## Organizational Responsibility

**Responsible Mission Directorate:**

Space Technology Mission Directorate (STMD)

**Lead Center / Facility:**

Langley Research Center (LaRC)

**Responsible Program:**

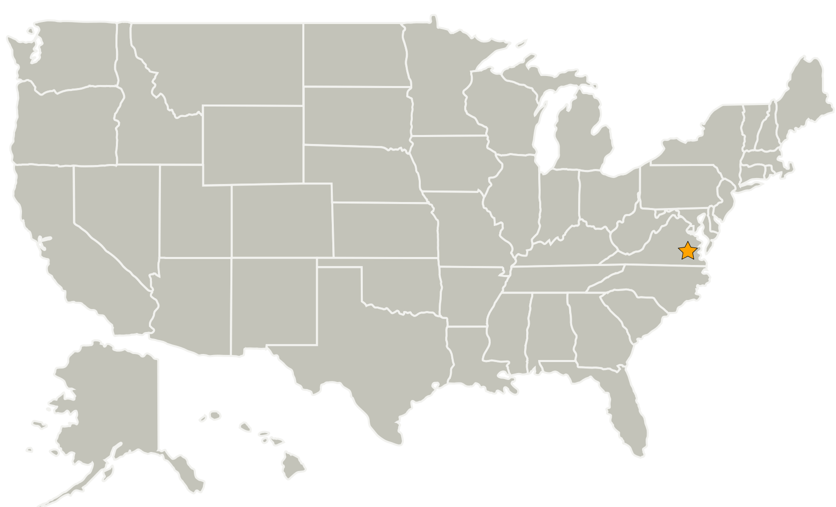
Center Innovation Fund: LaRC CIF

three orders of magnitude using this approach. **(2)** To accomplish the above goal, state-of-the-art composites damage progression research (see attached supplemental material) will be implemented in the three-dimensional fracture mechanics software FRANC3D, developed by Fracture Analysis Consultants, Inc. Machine learning techniques will be used to train the surrogate models utilizing FRANC3D simulations completed *a priori* and in parallel, leveraging high performance computing.

## Anticipated Benefits

The proposed technology could greatly accelerate progress toward the Advanced Composites Program (ACP) objective, which is to reduce the time and cost for certifying structural airframe components comprised of FRP composite materials. The proposed predictive innovations could replace a significant number of certification tests on the element and sub-component level. Furthermore, this research could add life prediction capabilities for complex composite structures to Digital Twin, which was recently selected as a Convergent Aeronautics Solutions (CAS) project. Digital Twin relies on data fusion with advanced predictive models, but the CAS funding focuses on a proof-of-concept for the truss braced wing (TWB) and not for composite-specific research. The aggregation of the proposed technologies in the Digital Twin framework could expand the design space for future NASA concepts, reduce testing burdens for certification and mission development, increase safety and reliability for aerospace structures, and enable condition-based maintenance. From this perspective, the impact of the proposed technology could be far-reaching in aerospace applications within NASA and in industry.

## Primary U.S. Work Locations and Key Partners



## Project Management

**Program Director:**

Michael R Lapointe

**Program Manager:**

Julie A Williams-byrd

**Principal Investigator:**

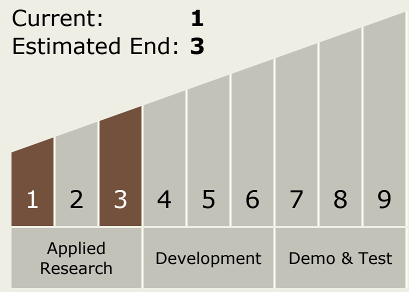
Patrick E Leser

**Co-Investigator:**

Jacob D Hochhalter

## Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **3**




## Technology Areas

**Primary:**

- TX09 Entry, Descent, and Landing
  └ TX09.4 Vehicle Systems
    └ TX09.4.5 Modeling and Simulation for EDL

| Organizations Performing Work | Role | Type | Location |
| --- | --- | --- | --- |
| ★Langley Research Center(LaRC) | Lead Organization | NASA Center | Hampton, Virginia |
| Fracture Analysis Consultants, Inc(FAC) | Supporting Organization | Industry | Ithaca, New York |